Revisiting Rose: Comparing the Benefits and Costs of Population-Wide and Targeted Interventions

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Context: Geoffrey Rose's two principal approaches to public health intervention are (1) targeted strategies focusing on individuals at a personal increased risk of disease and (2) population-wide approaches focusing on the whole population. Beyond his discussion of the strengths and weaknesses of these approaches, there is no empiric work examining the conditions under which one of these approaches may be better than the other.

Methods: This article uses mathematical simulations to model the benefits and costs of the two approaches, varying the cut points for treatment, effect magnitudes, and costs of the interventions. These techniques then were applied to the specific example of an intervention on blood pressure to reduce cardiovascular disease.

Findings: In the general simulation (using an inverse logit risk curve), lower costs of intervention, treating people with risk factor values at or above where the slope on the risk curve is at its steepest (for targeted interventions), and interventions with larger effects on reducing the risk factor (for population-wide interventions) provided benefit/cost advantages. In the specific blood pressure intervention example, lower-cost population-wide interventions had better benefit/cost ratios, but some targeted treatments with lower cutoffs prevented more absolute cases of disease.

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Conclusions: These simulations empirically evaluate some of Rose's original arguments. They can be replicated for particular interventions being considered and may be useful in helping public health decision makers assess potential intervention strategies.

Keywords: Population health, intervention studies, computer simulation, cardiovascular diseases.

GEOFFREY ROSE'S WORK INTRODUCED AN IMPORTANT IDEA into our thinking about etiology (Rose 1992, 2001). He pointed out that some etiologic research seeks to understand the causes of cases, trying to find out why certain individuals have disease. Other research attempts to uncover the causes of incidence, identifying the reasons that some populations have higher rates of disease. The *causes of cases* are those exposures that vary *within* a population, whereas the *causes of incidence* are the exposures that vary *between* populations. Whether exposures vary similarly within and among populations determines whether they are identified as causes of cases, causes of incidence, or both.

In the context of disease prevention and health promotion, a focus on the causes of cases leads to a different intervention approach than does a focus on the causes of incidence (Rose 1992, 2001). If causes of cases are the focus, then a targeted intervention strategy is implemented, identifying individuals at a personal increased risk of disease and offering treatment to reduce that risk. But if causes of incidence are the focus, then exposures across the entire population are modified to reduce the rate of disease across the whole population.

Each of these two approaches has strengths and weaknesses (Rose 1992, 2001). The targeted approach is appropriate to the individuals treated, because it is specific to their current risk factors, their motivation thus tends to be higher, and if there is any risk to the treatment, the benefit-to-risk ratio will be higher among those at a higher risk of disease. But the targeted approach requires ongoing screening to identify those at high risk; it does not deal with the root of the problem, and thus intervention for those at high risk must continue indefinitely; this approach does not reduce the burden of disease as much as one might expect, because most cases frequently come from the large number

of people in the population at lower risk of disease; and the targeted approach is behaviorally inappropriate because it asks people to make different choices, even though the norms of their social group remain unchanged.

In contrast, intervention strategies that target the whole population deal with the root of the problem by removing the underlying causes of disease across the population, dramatically reduce the disease burden because shifting risk levels for all members of the population even slightly can greatly alleviate the burden of disease, and are behaviorally appropriate because they alter the social norms (or other exposures) so that "normal" behavior becomes lower risk. Nonetheless, intervention strategies also have difficulties, including a small benefit to any individual (the so-called prevention paradox), with motivation correspondingly lower; and if there is any risk to the treatment, the benefit-to-risk ratio will be lower for those who initially were at lower risk of the disease.

Rose concludes that both targeted and population-wide approaches to prevention will continue to be necessary. He emphasizes, however, the importance of seeking and intervening in the causes of incidence, due to the potential for a dramatic and long-lasting reduction of the disease burden (Rose 1992, 2001). These ideas have been one of the motivations for the growing research on exposures that vary among populations, including research on community- or neighborhood-level exposures (Diez Roux 2004; Duncan, Jones, and Moon 1998; Macintyre, Ellaway, and Cummins 2002). These ideas also have provided support for the greater number of interventions targeting population-level exposures, such as norms (Merzel and D'Afflitti 2003). The limited success of several high-profile targeted intervention programs also has spurred movement toward population-wide intervention strategies (Syme 1996).

Rose's presentation of the two approaches to prevention provides a useful heuristic that can guide public health intervention planning. It does not, however, provide empiric guidance about when, and under what circumstances, targeted or population-wide approaches may be more desirable. For this article, in response to the issues laid out by Rose for assessing the best approach to intervention in specific situations, we quantified the benefits of preventing disease and the costs of treating disease for both the targeted and population-wide approaches, given the different costs of the interventions, the levels at which treatment is applied (cut points) for the targeted approach, and the magnitudes of the effect of reducing the risk factor for the population-wide

approach. To illustrate this approach, we used the specific example of potential interventions on blood pressure to reduce cardiovascular disease, and we also provide a quantitative approach that could be applied to any situation when different intervention strategies are being considered.

Methods

General Simulation

We started by simulating a population distributed across a continuous risk factor (examples of continuous risk factors might include blood pressure, cholesterol, and the like). Although simulations could be conducted with more than one risk factor, for this article and for simplicity and clarity, we restricted ourselves to only one. The simulated population had a normal distribution across the continuous risk factor with a mean of 10 and a standard deviation (SD) of 2. We then applied an intervention to the population, meaning that we shifted the total population's distribution across the risk factor in some way. This is akin to treating people before they develop disease, based solely on their current risk factor value. The two types of interventions we considered were targeted treatment and population-wide treatment, based on Rose's original discussion. In the targeted treatment, members of the population above a threshold or cut-point level of the risk factor were "treated," and their risk factor values were reduced by a fixed amount. In the simulation, the threshold selected was 12 (1 SD above the mean), and the risk factor values were reduced by 2 (1 SD) for those treated. In the population-wide treatment, all members of the population were "treated," and the risk factor levels of the entire population were reduced by a fixed amount. In the simulation, all risk factor values were reduced by 0.5 (0.25 SD). A range of values around these "fixed" values were considered in different simulations. These values were based on a general scenario in which the targeted treatment would be intensive and potentially pharmacological and would produce a large change in the risk factor for those treated. Conversely, the population-wide treatment was modeled to represent a diffuse and nonpharmacological intervention that would produce a more modest change in the risk factor for the whole population. By using this method, we could compare both

targeted and population-wide treatments of any magnitude, depending on the expected effects of specific potential interventions.

We then multiplied the risk curve by the simulated population before treatment and after targeted or population-wide treatment. Multiplying the risk curve by the pretreatment population and integrating the distribution calculates the expected amount of disease after the duration, given the risk curve and no treatment. Multiplying the risk curve by either posttreatment population and integrating the distribution calculates the expected amount of disease after the duration, given a particular treatment. We next compared the incidence of disease in both treated populations with the incidence of disease in the untreated population.

As a next step, we added to the model the total cost, total benefit, and a benefit/cost ratio for each intervention by assigning an average cost per person treated and an average benefit per case of disease prevented. After examining the costs of a wide range of prescription medications, we started with a cost of $1,000 per person, a representative cost for the targeted treatment of hypertension using a range of widely prescribed hypertension medications plus routine follow-up (Murray et al. 2003; Odell and Gregory 1995; Pearce et al. 1998). For the population-wide treatment, we started with a cost of $200 per person, again a representative cost based on literature on the cost of population-based interventions (Murray et al. 2003). A range of values around these starting values were considered in different simulations. The benefit of avoiding a case was set at $30,000, based on the average cost of a major cardiac event (Lindgren et al. 2005, 2007). However, any values of cost or benefit could be applied using this simulation method, depending on the actual interventions being considered and compared. We focused here on the comparison of the benefit/cost ratios of different intervention approaches by calculating the benefit/cost ratio of one intervention and dividing it by the benefit/cost ratio of another intervention. This ratio of benefit/cost ratios favors the numerator intervention when the value is above 1 and values the denominator intervention when it is below 1. In all our analyses, we considered population-wide benefit/cost ratios in the numerator; hence a ratio greater than 1 suggests that population-wide interventions have more favorable benefit/cost ratios than do targeted interventions, and vice versa. The interventions are equally monetarily efficient at 1. Note that this method need not use this measure, that interventions could be compared with cost/case-prevented ratios or other measures of interest using this simulation method.

Varying the input parameters in the simulation produces a range of benefit/cost ratios. The initial conditions varied in this article were the cost of the intervention (for the targeted and population-wide approaches), the cut point above which people were treated (for the targeted approach), and the magnitude of the shift effect on reducing the risk factor (for the population-wide approach). We plotted the benefit/cost ratios and ratio of benefit/cost ratios as surfaces in which two of the initial conditions were varied along each of the x and y axes.

Specific Example

In the second part of the analysis, we considered blood pressure as the risk factor and the outcome cardiovascular disease as a specific example of how this simulation method could be used when comparing two concrete potential interventions. We used the Framingham risk equation to generate a risk curve for blood pressure based on empirical research (Kannel, McGee, and Gordon 1976). The risk curve (log odds intercept, log odds slope) for systolic blood pressure was calculated for a smoker, aged fifty, with serum cholesterol of 6.37 mmol/l, no glucose intolerance, and no left ventricular hypertrophy (LVH) (Kannel, McGee, and Gordon 1976). The need to specify the age, smoking status, serum cholesterol, glucose intolerance, and LVH arose from the need, for simplicity, to have one risk curve for the whole population. Simulations could be extended to accommodate additional characteristics that modify risk, and we will describe such extensions in a future article.

We then simulated variations of the targeted approaches to the treatment of blood pressure and of population-wide interventions to lower blood pressure and observed their implications for the benefit/cost ratios and ratios of benefit/cost ratios for the two intervention approaches. The total population values for blood pressure (total mean 130.3, total SD 16.5) were obtained from a population-based study (Weinehall et al. 1999). For the targeted approach, we varied the cut point for treatment, and for the population-wide approach, we varied the cost per person. The effect of the targeted treatment on the reduction in blood pressure among those treated was 2.88 SD (Rx effect) and was estimated from the results from the Systolic Hypertension in the Elderly Program (SHEP) study (SHEP Cooperative Research Group 1991). The cost per person treated for the targeted intervention was calculated as $1,200, which is

TABLE 1
Parameters of the Models

Parameters	Basic Assumptions	Source
Total people[a,b]	100,000	Hypothetical population size
Total mean[a,b]	130.3 mmHg	(Weinehall et al. 1999)
Total SD[a,b]	16.5	(Weinehall et al. 1999)
Log odds intercept[a,b]	−5.768	(Kannel, McGee, and Gordon 1976)
Log odds slope[a,b]	0.016	(Kannel, McGee, and Gordon 1976)
Treatment cutoff[a]	120 . . . 170	(Chobanian et al. 2003)
Rx effect[a]	47.59 mmHg (2.88 SD)	(SHEP Cooperative Research Group 1991)
Cost per person treated[a]	$1,200	(Pearce et al. 1998)
Total shift effect[b]	8.4 mmHg (0.51 SD)	(Appel et al. 1997)
Cost per person[b]	$20–$220	(Murray et al. 2003)

Notes: [a]Targeted approach.
[b]Population approach.

the cost of a common blood pressure medication taken over eight years (Pearce et al. 1998). For the population-wide approach, the effect of a population-wide dietary intervention on the reduction in blood pressure was 0.51 SD across the population and was estimated from the Dietary Approaches to Stop Hypertension (DASH) study (Appel et al. 1997). The cost per person of a population intervention was considered across a range of values suggested by various completed population-based interventions (Murray et al. 2003). Table 1 shows the specific parameters used in this simulation and their sources.

The outputs of each of the analyses include the cost per case prevented (cost per case prevented), the fraction of the total population treated for the targeted intervention (total treated), the fraction of the total population in which disease was prevented (benefit fraction), the fraction of the population that would have had disease but that was prevented (disease prevented), the total cost of the treatment (total cost), the total benefit of the treatment (monetary benefit), and the benefit-to-cost ratio (benefit/cost), which were produced by the methods described earlier. All simulations and analyses were conducted using Maple v.11 (code is available from the corresponding author on request).

Results

General Simulation

The figures depict the results of simulations using a logistic risk curve (logistic risk curve equation: $1/(1 + \exp(4 - 0.3 * x))$), varying aspects of the intervention (treatment cut point for the targeted approach, magnitude of shift effect for the population-wide approach), and cost (cost per person treated for both approaches). The two types of graphs depict surfaces. Those graphs whose z axis is labeled "Benefit/cost ratio" show a single treatment approach for various values of two input parameters. In these graphs the approach is monetarily efficient if the z axis value is larger than 1 (implying that benefit is greater than cost) and inefficient if the z axis value is less than 1 (cost is greater than benefit). Those graphs whose z axis is labeled "Ratio of benefit/cost ratios" compare the population-wide (numerator) and the targeted (denominator) treatment approaches.

Figure 1 shows the benefit/cost ratio surface for a targeted treatment approach as both the cutoff for treatment and the average targeted treatment cost per person are varied. The figure indicates that along the treatment cutoff (Treatment cutoff) axis, the ratio reaches a maximum at around 13. This is exactly where the logistic risk curve reaches its maximum slope. As would be expected, across all cutoffs the benefit/cost ratio increases as the cost per person treated decreases.

Figure 2 shows the ratio of benefit/cost ratios between a population-wide approach and a targeted approach as the initial conditions of cost per person and cutoff for treatment are varied for the targeted approach. The values for the population-wide approach are fixed at 0.5 (0.25 SD) for the magnitude of the shift effect and at \$200 for the cost per person treated; thus the population-wide approach benefit/cost ratio surface is constant across the shown space. We can see the ratio of benefit/cost ratios exceeding the 1 plane, favoring the population-wide approach for costs of the targeted treatment exceeding \$600 to \$800 per person, depending on the cutoff points (Treatment cutoff).

Figure 3 shows the benefit/cost ratio of a population-wide treatment as the treatment effect and the cost per person are varied. The curve is above 1 almost everywhere, indicating that this population-wide approach is cost effective on almost all the space shown. The curve has a $1/x$ shape along the cost axis and an almost linear shape along the shift effect axis.
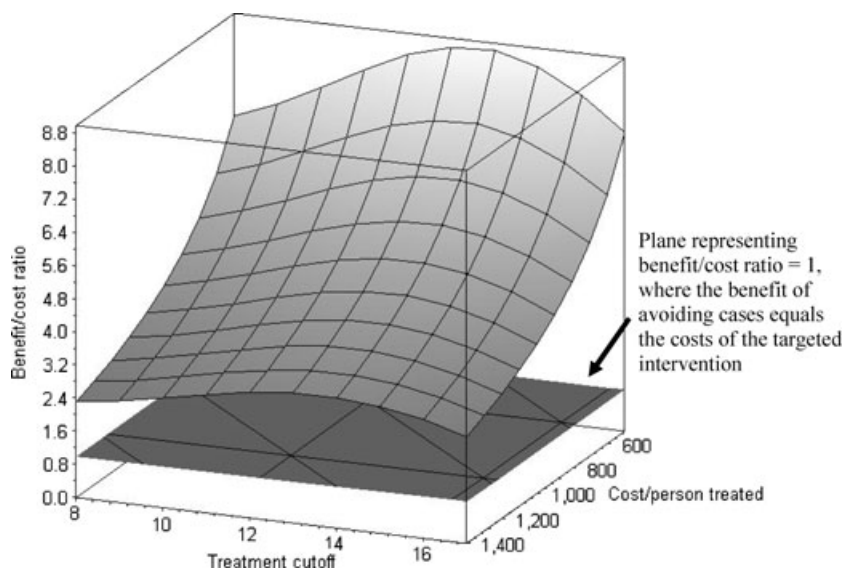
FIGURE 1.   Targeted Intervention: Surface of Benefit in Cases Averted/Cost of the Intervention for a Targeted Intervention as the Cost of the Intervention (Cost/Person Treated) and the Cutoff for Treatment (Treatment Cutoff) Are Varied

The $1/x$ shape along the cost axis demonstrates that the increase in the benefit/cost ratio with a decreasing cost rises (accelerates) as the costs fall.

Figure 4 shows the ratio of benefit/cost ratios between a population-wide approach and a targeted approach as the initial conditions of cost per person treated and the magnitude of the shift effect are varied for the population-wide approach. The values for the targeted approach are fixed at 12 for the treatment cutoff and at $1,000 as the cost per person treated; thus the targeted approach benefit/cost ratio surface is constant across the shown space. As the cost of the population-wide treatment per person increases, the magnitude of the shift effect must be larger for the population-wide approach to be favored. For example, when the shift effect is 0.85 (0.425 SD), the cost must be $300 or lower to favor the population-wide approach. In contrast, where the shift effect is 1.5 (0.725 SD), the cost can be as high as $500 per person and still favor the population-wide approach.
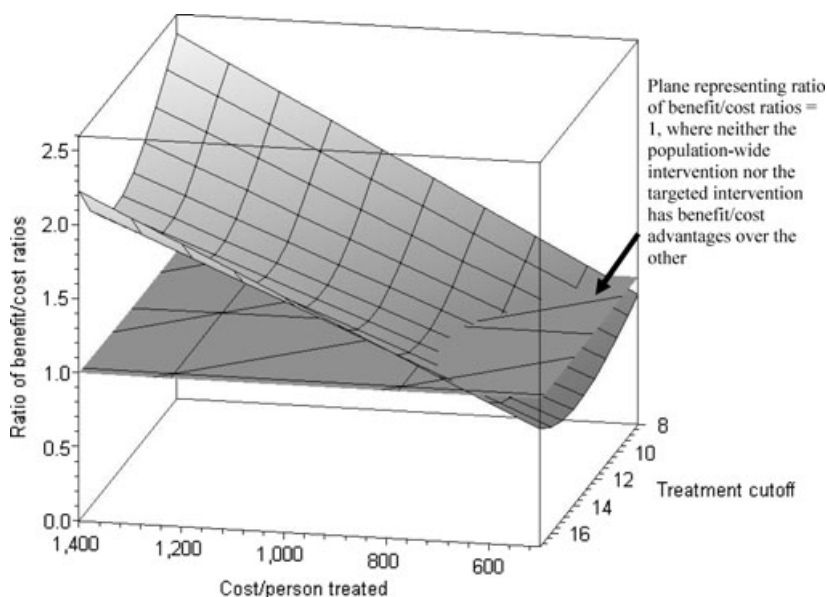
FIGURE 2.   Comparison of the Benefit/Cost of the Targeted Intervention and the Population-Wide Intervention while Varying the Treatment Cutoff and the Cost per Person Treated for the Targeted Intervention; Values Greater than 1 Favor the Population-Wide Treatment, and Values below 1 Favor the Targeted Treatment

Specific Example

Having presented some hypothetical scenarios, we now move to the concrete example considering blood pressure as a risk factor for cardiovascular disease. Table 2 presents some scenarios for targeted treatments, presenting all of the inputs and some of the outputs when the total population and the logistic risk curve are known. In table 2 we vary the systolic blood pressure cutoff for treatment (Treatment cutoff) from 120 mmHg to 180 mmHg, which represent levels from prehypertensive to extremely hypertensive (Chobanian et al. 2003). This affects the number of people treated (total treated) and consequently affects the cost of this treatment scheme (total cost) and the benefits of the treatment (monetary benefit). We also see a difference in the fraction of the total population in which disease is prevented (benefit fraction) and the fraction of the population that would have had disease but that was prevented

TABLE 2
Inputs and Outputs of a Targeted Intervention as the Cutoff for Treatment Is Varied

| Inputs							
Total people	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Total mean	130.3	130.3	130.3	130.3	130.3	130.3	130.3
Total SD	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Log odds intercept	−5.768	−5.768	−5.768	−5.768	−5.768	−5.768	−5.768
Log odds slope	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Treatment cutoff	120	130	140	150	160	170	180
Rx effect	47.59	47.59	47.59	47.59	47.59	47.59	47.59
Cost per person treated	$1,200	$1,200	$1,200	$1,200	$1,200	$1,200	$1,200
Outputs							
Cost per case prevented	$86,086.3	$79,515.32	$71,932.14	$64,131.58	$56,646.47	$49,755.7	$43,568.68
Total treated	0.734	0.507	0.278	0.116	0.036	0.008	0.001
Benefit fraction	0.01	0.008	0.005	0.002	0.001	0.0002	0.00004
Disease prevented	0.42	0.315	0.191	0.089	0.031	0.008	0.001
Total cost	$88,051,896	$60,870,371	$33,396,819	$13,950,100	$4,311,638	$967,535	$155,657
Monetary benefit	$30,684,984	$22,965,527	$13,928,467	$6,525,793	$2,283,445	$583,371	$107,180
Benefit/cost	0.348	0.377	0.417	0.468	0.53	0.603	0.689
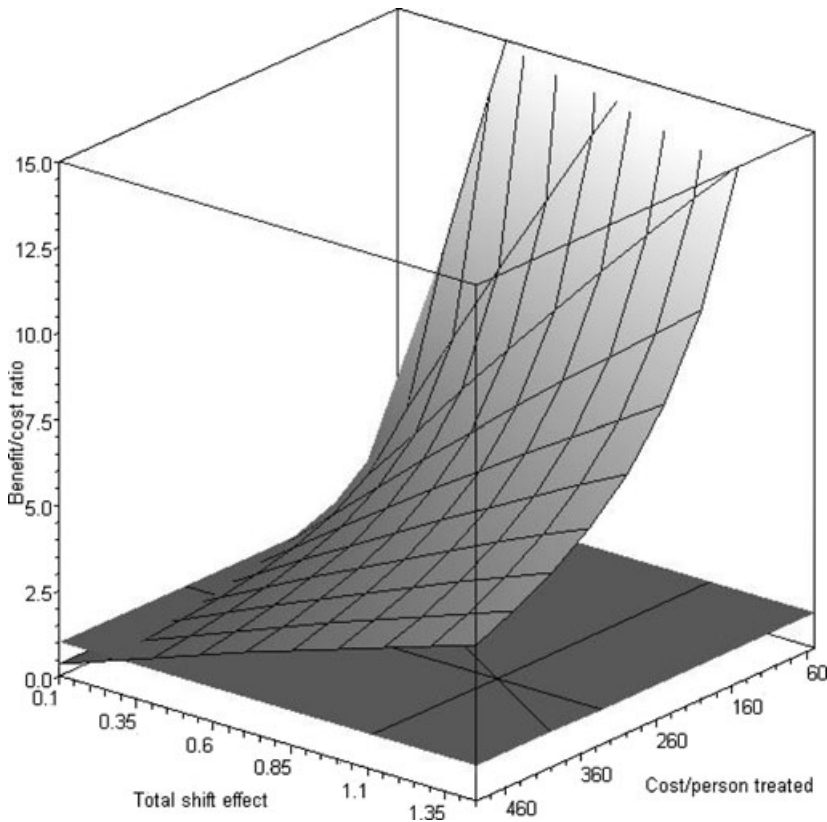
FIGURE 3. Population-Wide Intervention: Surface of Benefit in Cases Averted/Cost of the Intervention for a Population-Wide Intervention as the Cost of the Intervention (Cost/Person Treated) and the Magnitude of the Effect of Treatment on the Risk Factor (Total Shift Effect) Are Varied

(disease prevented). From the prehypertensive cutoff for treatment up to the severe hypertensive cutoff, the fraction of the total population in which disease was prevented (benefit fraction) ranges from 1.0 to 0.004 percent, and the fraction of the population that would have had disease but that was prevented (disease prevented) ranges from 42.0 to 0.1 percent. These benefit measures favor the lowest cutoff of 120 mmHg, although this approach is least efficient in terms of benefit/cost. From the prehypertensive cutoff for treatment up to the
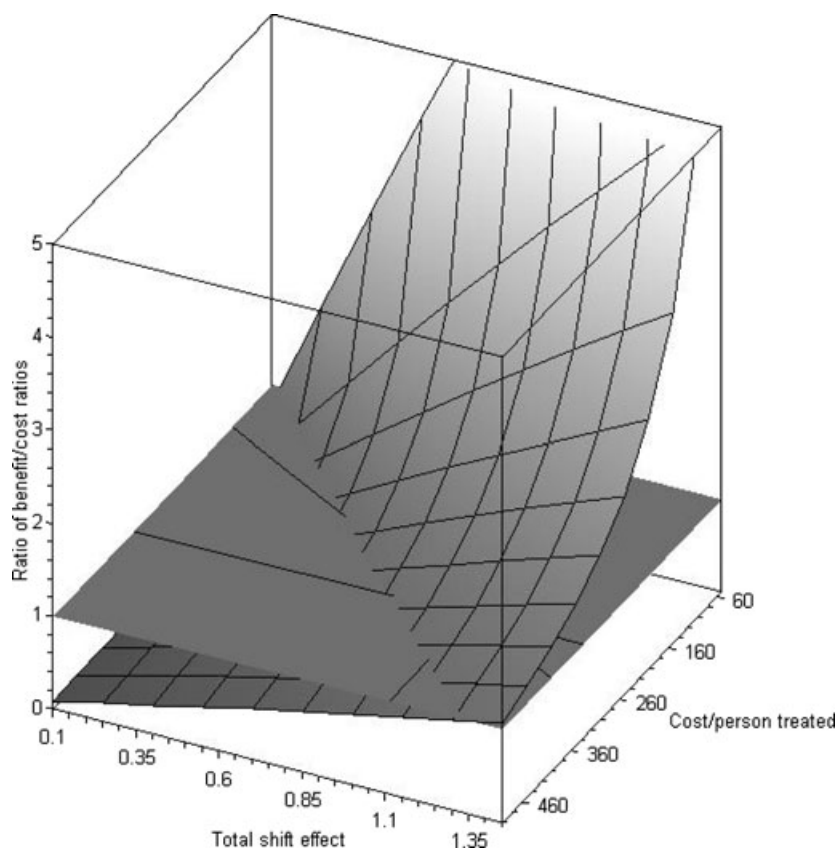
FIGURE 4.   Comparison of the Benefit/Cost of the Population-Wide Interven-
tion and the Targeted Intervention while Varying the Cost of the Intervention
(Cost/Person Treated) and the Magnitude of the Effect of Treatment on the Risk
Factor (Total Shift Effect) for the Population-Wide Intervention; Values Greater
than 1 Favor the Population-Wide Treatment, and Values below 1 Favor the
Targeted Treatment

severe hypertensive cutoff, the benefit/cost increases from 0.348 up to
0.689.

   Table 3 presents some scenarios for the population-wide intervention,
presenting all of the inputs and some of the outputs when the total
population and the logistic risk curve are known. Only the cost of
treatment per person is varied. The fraction of the total population in

TABLE 3
Inputs and Outputs of a Population-Wide Intervention as the Cost per Person Is Varied

Inputs						
Total people	100,000	100,000	100,000	100,000	100,000	100,000
Total mean	130.3	130.3	130.3	130.3	130.3	130.3
Total SD	16.5	16.5	16.5	16.5	16.5	16.5
Log odds intercept	−5.768	−5.768	−5.768	−5.768	−5.768	−5.768
Log odds slope	0.016	0.016	0.016	0.016	0.016	0.016
Total shift effect	8.4	8.4	8.4	8.4	8.4	8.4
Cost per person	20	60	100	140	180	220
Outputs						
Cost per case prevented	$6,810.4	$20,431.21	$34,052.02	$47,672.83	$61,293.64	$74,914.45
Benefit fraction	0.003	0.003	0.003	0.003	0.003	0.003
Disease prevented	0.121	0.121	0.121	0.121	0.121	0.121
Total cost	$200,000	$6,000,000	$10,000,000	$14,000,000	$18,000,000	$22,000,000
Monetary benefit	$8,783,777	$8,783,777	$8,783,777	$8,783,777	$8,783,777	$8,783,777
Benefit/cost	4.392	1.464	0.878	0.627	0.488	0.399

which disease was prevented (benefit fraction) is 0.3 percent, and the fraction of the population that would have had disease but that was prevented (disease prevented) is 12.1 percent. These values are constant, since the treatment that produced these measures is not varied. Not surprisingly, all the cost measures favor the lowest cost; the benefit/cost ranges from 4.392 for the least expensive population-wide intervention to 0.399 for the most expensive intervention.

Together, the tables can be used to examine the scenarios and ways in which one treatment is better than the other. The population-wide treatments costing $100 or less are more benefit/cost effective than any of the targeted treatments. But some of the targeted treatments with lower cutoffs for treatment provide more benefit for the benefit fraction and the disease prevented. For higher costs of the population-wide treatment, the cutoff chosen for blood pressure determines the relative benefit/cost effectiveness of the two approaches. In all the targeted and population-wide intervention scenarios, the benefit exceeds the cost for a population-wide treatment only with a cost of $60 per person or less.

Discussion

In this analysis, we quantitatively considered the issue raised by Rose about the relative benefits of a population-wide approach to intervention compared with a targeted approach. We explored the two approaches using simulations in which we varied aspects of the costs and treatment effects for each intervention approach. Finally, we applied these methods to a specific example, comparing two approaches to intervention regarding blood pressure to reduce cardiovascular disease.

In a series of general simulations, we found that either approach could be favored, depending on the parameters of cost and treatment effect. The targeted approaches tended to be favored when people were treated if they had risk factor values at or above where the slope of the (inverse logit) risk curve was at its steepest and the costs of treatment per person could be kept low. Population-wide approaches tended to be favored when the intervention had larger effects on reducing the risk factor and the costs of treatment per person could be kept low. This suggests that in any situation, both approaches should be considered. Simulations like those presented here could be used to consider quantitatively the favorability of one intervention approach over another if the input parameters

for costs, the treatment cut points, and the effect magnitudes could be estimated accurately for all exposures and outcomes of interest. Estimates of such parameters are probably more readily available for areas in which more intervention work has already been conducted. For a new type of intervention, accurately estimating input parameters would be a challenge, and a wider range of potential values would need to be considered.

In our specific example, we used the risk curve for cardiovascular disease based on the Framingham equation and applied it to a real population distribution of blood pressure. We then applied a targeted intervention and a population-wide intervention to blood pressure and modeled the effects of each intervention on the change in blood pressure distribution based on realistic values of blood pressure reductions from medication (for the targeted approach) and from the results of a population-wide intervention (for the population-wide approach). Following these interventions, we examined the change in cardiovascular disease incidence. In addition, we varied the cut point for treatment for the targeted approach and varied the cost per person treated for the population-wide approach to examine which scenarios favored which approach. The costs and benefits of the two approaches were then compared. The results of this specific example suggested that for the targeted scenarios, the most cost-effective measures typically provided the least benefit and that for all targeted and population-wide interventions, only a population-wide intervention with a very low cost produced more benefit than cost.

One important additional consideration in comparing approaches, which Rose suggested, is the length of time that the intervention will be required (Rose 2001). By definition, the targeted approach will require screening for those at high risk and treatment of those at high risk indefinitely into the future. In contrast, population-wide approaches are intended to change the fundamental underlying causes of the risk factor, so that after a certain period of time, those lower values of the risk factor across the population would become the norm without further intervention (at least in the ideal scenario). From this perspective, comparing the cost of each intervention over the same time period may be misleading. The time anticipated to be required for the population-wide intervention could be incorporated into the cost/benefit calculations. These total costs of a population-wide approach could be compared with the annual costs of a targeted approach, offering an opportunity to determine how much time would need to elapse before a population-wide approach became

more cost effective than a targeted approach, even if a population-wide approach were more expensive in any particular intervention year.

Preventing a case of disease also is not without cost. Even though the cost of caring for one disease may be prevented, those who live longer may have more need for long-term care. If such costs could be estimated based on current medical expenditures for those living longer, these potential costs could be integrated into this modeling approach.

The costs of screening for those at high risk of disease should also be incorporated into models of the targeted approach, as people cannot be treated until they have been identified as being in a high-risk group. In our specific example, we considered only the costs of prescribing a blood pressure medication, but the costs of screening at regular intervals could be considered as well (Kristiansen, Eggen, and Thelle 1991). While these costs may not be high for blood pressure and cardiovascular disease—at least for those who receive regular medical checkups—it may be higher for other diseases and their risk factors of interest.

For simplicity, we assumed that all individuals took their blood pressure medication and that it had exactly the expected effect on everyone who took it. We also assumed that everyone in the population-wide intervention had the same reduction in blood pressure that was expected based on an intervention, although it is important to note that this reduction was observed in a situation in which the levels of participation in and compliance with the intervention were at their actual levels, not some hypothetical maximum level. Both levels of compliance and magnitudes of effect could be modified over a range of values and incorporated into the model, allowing estimation of more realistic benefits and effects of interventions for real-world applications. Rose indicated that people at high risk were typically more motivated but that for some interventions (e.g., diet and exercise changes), they were being asked to act in a way that was behaviorally unsuitable for their social context (Rose 2001). He also noted that the population-wide approach may be plagued by low motivation owing to the "prevention paradox" (Rose 2001). But if population-wide change does gain momentum, norms may start to change, encouraging behavioral or other changes for everyone in the population. The two competing issues for each type of intervention would need to be considered on balance to estimate the potential net effect on compliance and the magnitude of the effect.

In all these simulations, we assumed there was no negative effect of treatment. However, for many real-world interventions, particularly those involving medication but also for population-level interventions,

there are substantial potential negative effects. The model could accordingly be modified to allow negative outcomes among a certain percentage of those treated, based on what is known about the medication or other intervention with potential negative consequences.

This simulation examined the effects of reducing blood pressure on cardiovascular disease, but reducing blood pressure clearly could affect many different health outcomes (e.g., cerebrovascular disease). In addition, reducing blood pressure could also reduce complications from its interaction with other conditions. To the extent that this is true, the benefits of the intervention are likely underestimated using this approach.

For risk factors with U-shaped or J-shaped associations with outcomes, a reasonable approach to intervention would be targeting people with both high and low values of the risk factor. In many respects, this is how risk factors like body mass index have been handled. These types of interventions could be modeled using the same techniques presented here to determine which groups with high and low values of the risk factor should be treated when also considering the costs and effects of treatment.

One obvious concern about this simulation approach is that for any particular relation between risk factor and health outcome, we typically do not know the shape of the risk curve (i.e., how changing the risk factor will precisely affect the likelihood of disease) at the same level of precision as that of the curves specified in these simulations. Some additional simulations (not presented here but available from the authors on request), however, were reassuring in this regard. The simulations suggested that for a range of different types of relations between risk factors and health outcomes (i.e., different risk curve shapes such as inverse logistic risk curve, U-shaped risk curve, and threshold risk curve), the results were quite similar for curves of similar magnitude. Therefore, if we can reasonably determine the more general form of the risk curve and approximate the necessary parameters, the results should not be misleading.

In conclusion, we presented a quantitative method for comparing the results of potential interventions from the point of view of costs and benefits, particularly comparing targeted approaches with population-wide approaches. Our method builds on Rose's work, particularly the concepts he clearly laid out as the positives and negatives of these two intervention strategies (Rose 1992, 2001). We also quantified some of

these concepts to compare cost effectiveness and benefit in disease prevention for real-world applications. In settings where resources are plentiful, both targeted and population-wide interventions might be feasible; comparing their strengths and weaknesses and determining the optimal balance of costs and benefits for each approach would still be informative in this situation. Although this work is computationally intensive, we believe that such simulations hold promise for helping public health decision makers evaluate potential intervention strategies and can motivate researchers to provide data that provide better parameters for such comparisons.

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